AUG 11 1965

EUR/AEC Report
CEND-3336-241

JOINT U.S. - EURATOM

JOINT UNITED STATES
ATOMIC ENERGY COMMISSION
RESEARCH AND DEVELOPMENT PROGRAM

PROGRESS REPORT

MASTER

DEVELOPMENT AND TESTING OF A TEMPERATURE
TRANSIENT METHOD FOR PERFORMING
IN-PILE THERMAL CONDUCTANCE TESTING

For Period
April 1 to June 30, 1965

NOTICE

This report was received under the provisions
of the *Joint U.S./Euratom R&D*
arrangement and is subject to the terms thereof.

CAUTION

This report contains possibly patentable
information and should not be further
disseminated without the approval of the
Document Management Branch, DTI Extension
Oak Ridge, or the Assistant General Counsel
for Patents, Washington, D. C.

Issued July 1965

NUCLEAR
DIVISION

COMBUSTION ENGINEERING, INC.

~~NOT APPROVED FOR PUBLIC RELEASE. AVAILABLE
FOR OFFICIAL PURPOSES ONLY.~~

NOTICE

This report contains information of a preliminary
nature and was prepared primarily for internal use
at the originating installation. It is subject to re-
vision or correction and therefore does not repre-
sent a final report. It is passed to the recipient in
confidence and should not be abstracted or further
disclosed without the approval of the originating
installation or DTI Extension, Oak Ridge.

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

CONFIDENTIAL

CONFIDENTIAL

CONFIDENTIAL

LEGAL NOTICE

This document was prepared under the sponsorship of the United States Atomic Energy Commission pursuant to the Joint Research and Development Program established by the Agreement for Cooperation signed November 8, 1958 between the Government of the United States of America and the European Atomic Energy Community (Euratom). Neither the United States, the U. S. Atomic Energy Commission, the European Atomic Energy Community, the Euratom Commission, nor any person acting on behalf of either Commission:

- A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this document, or that the use of any information, apparatus, method, or process disclosed in this document may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method or process disclosed in this document.

As used in the above, "person acting on behalf of either Commission" includes any employee or contractor of either Commission or employee of such contractor to the extent that such employee or contractor or employee of such contractor prepares, handles, disseminates, or provides access to, any information pursuant to his employment or contract with either Commission or his employment with such contractor.

CONFIDENTIAL

NOT TO BE RELEASED PENDING PATENT CLEARANCE

PRELIMINARY REPORT

U. S. EURATOM EXCHANGE

To expedite dissemination of technical information to those persons requiring it, this report has been issued without the administrative review necessary to protect the interests of the U. S. Government, the European Atomic Energy Community (Euratom) and Combustion Engineering, Inc. The recipient of this report agrees that it is passed on to him in confidence, that he will maintain that confidence and make no disclosures or publication of the contents, that would be detrimental to the interests of the U. S. Government, the European Atomic Energy Community (Euratom), and Combustion Engineering, Inc.

LEGAL NOTICE

This document was prepared under the sponsorship of the Atomic Energy Commission pursuant to the Joint Research and Development Program established by the Agreement for Cooperation signed November 8, 1958, between the Government of the United States of America and the European Atomic Energy Community (Euratom). Neither the United States, the U. S. Atomic Energy Commission, the European Atomic Energy Community, the Euratom Commission nor any person acting on behalf of either Commission:

- a. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this document, or that the use of any information, apparatus, method or process disclosed in this document may not infringe privately owned rights; or
- b. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method or process disclosed in this document.

As used in the above, "person acting on behalf of either Commission" includes any employee or contractor of either Commission or employee of such contractor to the extent that such employee or contractor or employee of such contractor prepares, handles, disseminates, or provides access to, any information pursuant to his employment or contract with either Commission or his employment with such contractor.

CEND-3336-241
Joint U.S. -Euratom
UC-25, Metals, Ceramics
and Materials
TID-4500, 43rd Edition

EXTERNAL DISTRIBUTION:

No. of Copies

United States Atomic Energy Commission
Brussels Office
AEO, New York 09667
Attention: Senior Atomic Energy Commission
Representative

20

Mr. L. Graup, Authorized Representative
United States Atomic Energy Commission
New York Office
376 Hudson Street
New York, New York 10014

1

United States Atomic Energy Commission
New York Operations Office
376 Hudson Street
New York, New York 10014
Attention: Reports Library

1

Mr. J. M. Simmons, Chief
Fuels and Materials Development Branch
U. S. Atomic Energy Commission
Division of Reactor Development and Technology
Washington, D. C. 20545

2

Mr. W. R. Voigt, Chief
Water Reactors Branch
U. S. Atomic Energy Commission
Division of Reactor Development and Technology
Washington, D. C. 20545

2

Dr. R. C. Dalzell, Assistant Director for
Foreign Activities
U. S. Atomic Energy Commission
Division of Reactor Development and Technology
Washington, D. C. 20545

2

U. S. Atomic Energy Commission
Office of Foreign Activities
Division of Reactor Development and Technology
Washington, D. C. 20545

1

EXTERNAL DISTRIBUTION (Continued):

No. of Copies

Mr. Harmon S. Potter, Chief
New York Patent Group
Brookhaven National Laboratory
Upton, L.I., New York 11973

1

Dr. William Holton
Assistant General Counsel for Patents
U. S. Atomic Energy Commission
Washington, D.C. 20545

1

U. S. Atomic Energy Commission
Division of Technical Information Extension
Post Office Box 62
Oak Ridge, Tennessee 37831

3

Mr. A. J. Alexander
U. S. Atomic Energy Commission
CANEL Project Office
Post Office Box 611
Middletown, Connecticut

1

Mr. Bruce Anderson
U. S. Atomic Energy Commission
Programs Division
Chicago Operations Office
9700 South Cass Avenue
Argonne, Illinois 60439

\ 1

Mr. D. F. Cope
U. S. Atomic Energy Commission
Oak Ridge Operations Office
Reactor Division
Oak Ridge, Tennessee 37831

1

U. S. Atomic Energy Commission
Office of Technical Information
Washington, D.C. 20545

2

Dr. W. J. O'Leary
Allis-Chalmers Manufacturing Company
Atomic Energy Division
6935 Arlington Road
Bethesda, Maryland 20014

1

EXTERNAL DISTRIBUTION (Continued):

	<u>No. of Copies</u>
Mr. S. Paprocki Battelle Memorial Institute 505 King Avenue Columbus, Ohio	1
Mr. W. G. Holmes E. I. duPont de Nemours & Company, Inc. Savannah River Laboratories Aiken, South Carolina	1
Mr. S. Naymark General Electric Company Vallecitos Atomic Laboratory Atomic Power Equipment Department Post Office Box 1131 San Jose, California	1
Mr. E. O. Sullivan General Electric Company Vallecitos Atomic Laboratory Atomic Power Equipment Department Post Office Box 1131 San Jose, California	1
Dr. W. R. DeHollander General Electric Company Vallecitos Atomic Laboratory Atomic Power Equipment Department Post Office Box 1131 San Jose, California	1
Dr. D. R. deHalas Pacific Northwest Laboratory Battelle Memorial Institute P.O. Box 999 Richland, Washington 99352	1
Dr. R. F. Stoops, Head Pyrochemical Research North Carolina State College Raleigh, North Carolina	1

CEND-3336-241
Joint U.S. -Euratom
UC-25, Metals, Ceramics
and Materials
TID-4500, 43rd Edition

EXTERNAL DISTRIBUTION (Continued):

	<u>No. of Copies</u>
Mr. Phillip Thompson Nuclear Metals, Inc. Concord, Massachusetts	1
Mr. Lewis J. Jones Nuclear Materials and Equipment Corporation Apollo, Pennsylvania	1
Oak Ridge National Laboratory Chemical Technology Division Oak Ridge, Tennessee	1
Oak Ridge National Laboratory Metallurgy Division Oak Ridge, Tennessee	1

DEVELOPMENT AND TESTING OF A TEMPERATURE
TRANSIENT METHOD FOR PERFORMING
IN-PILE THERMAL CONDUCTANCE TESTING

TABLE OF CONTENTS

	<u>Page No.</u>
LIST OF FIGURES AND TABLE	vii
PREFACE	viii
ABSTRACT	ix
I. SUMMARY	1
II. INTRODUCTION	2
III. TEST EQUIPMENT	3
IV. EXPERIMENTAL STUDIES	4
V. DISCUSSION	9
VI. FUTURE WORK	11

DEVELOPMENT AND TESTING OF A TEMPERATURE
 TRANSIENT METHOD FOR PERFORMING
 IN-PILE THERMAL CONDUCTANCE TESTING

List of Figures and Table

<u>Figure</u>	<u>Title</u>	<u>Following Page No.</u>
1	Gear Layout	3
2	Cladding Temperature vs. Time Step and Pulse Inputs	5
3	Temperature Response at Clad With One Second Pulse Input	5
4	Cladding Temperature vs. Time For Various Input Frequencies	6
5	Cladding Temperature vs. Time For Two Input Levels at Fixed Frequency	7
6	Cladding Temperature vs. Time Fixed Frequency Various Locations	8
<u>Table</u>		
I	Gear Ratios vs. Corresponding Shaft Frequency Speeds for 72 RPM Input, Fixed 6:1 Reduction Before Change Gears	3

PREFACE

The United States and the European Atomic Energy Community (EURATOM) on May 29 and June 18, 1958, signed an agreement which provides a basis for cooperation in programs for the advancement of the peaceful applications of atomic energy. This agreement, in part, provides for the establishment of a Joint U.S. -Euratom research and development program which is aimed at reactors to be constructed in Europe under the Joint Program.

The work described in this report represents the Joint U.S. -Euratom effort which is in keeping with the spirit of cooperation in contributing to the common good by the sharing of scientific and technical information and minimizing the duplication of effort by the limited pool of technical talent available in Western Europe and the United States.

DEVELOPMENT AND TESTING OF A TEMPERATURE
TRANSIENT METHOD FOR PERFORMING
IN-PILE THERMAL CONDUCTANCE TESTING

By

C. E. Burdg and S. S. Christopher

ABSTRACT

The concept now being investigated is one whereby measurement of the transient temperature response at the surface of an operating fuel element, following a reactor power change, will yield thermal conductance values. This two-phase investigation consists first of out-of-pile demonstrations of feasibility followed by in-pile confirmation of the method. Concurrent mathematical analyses of the thermal model will provide the bases for data interpretation, as well as guides for the design of the experimental portions of the program.

Exploratory tests of an out-of-pile element, using ZrO_2 to simulate the fuel, have led to the conclusion that the presence of random thermal disturbances at the element cladding are sufficient to preclude obtaining accurate measurements of temperature-time relations using simple recording equipment. Tests performed with cyclic power inputs in the frequency range from .0348 radians/second to .503 radians/second demonstrated that trends in the response characteristics are as predicted analytically, but the analytical values could not be confirmed. Special signal processing equipment, including a low-pass filter, may permit obtaining meaningful data.

I. SUMMARY

During this reporting period, test apparatus modifications have been completed and provide means of varying the input power to the test element in a number of ways. Most important, is the ability to achieve cyclic input in the frequency range from 0.0348 radians/second to 1.257 radians/second. Using this equipment, a series of exploratory tests were performed on a test element containing ZrO_2 to simulate the fuel. It was determined that stabilized ZrO_2 could serve as a comparison material based on its thermal and mechanical properties which are similar to UO_2 . These tests demonstrated that some of the trends predicted by prior analytical work were valid; however, instrumental difficulties preclude verification of the specific analytical values.

Investigation of means of clearing the instrumental difficulties is underway. It is expected that special signal processing equipment will permit obtaining meaningful data from further experiments.

II. INTRODUCTION

The objective of this program is to develop a method of determining the thermal conductance of UO_2 fuel elements while operating in a reactor. Transient response of element surface temperature, following a power change, is the parameter to be utilized.

The present program consists of an out-of-pile and in-pile investigation. The out-of-pile phase is intended to prove the feasibility of the method to be employed in-pile. It is also intended to demonstrate that reliable values for fuel element conductances can be obtained through transient testing techniques. Upon completion of the first phase, a review of the results will be made and concurrence of the Commission obtained prior to initiation of the second phase of the program. This second, or in-pile, phase will utilize the correlations and experience gained during the out-of-pile investigation. The methods and analytical techniques should prove particularly useful.

During the previous reporting period design work was performed to establish the desired characteristics of both test elements and test apparatus. It was determined that stabilized ZrO_2 could serve as a comparison pellet material, having many of the thermal and mechanical properties of UO_2 but with a significantly lower thermal conductivity. Fabrication of test element pellets, of both ZrO_2 and UO_2 , was started.

During this current reporting period, the construction of a mechanical low frequency function generator was completed. This apparatus is needed to introduce cyclic inputs to the heater of the test element. Using this equipment, a test element containing ZrO_2 was subjected to exploratory thermal tests to determine the adequacy of present instrumentation.

III. TEST EQUIPMENT

A low frequency mechanical function generator has been constructed to provide a means of achieving cyclic input to the heater of the test element. The equipment consists of a synchronous motor which is geared to drive a cam and adjustable autotransformer. Frequency is varied by changing the gear ratio; the use of two-stage gearing, Figure 1, results in simple coverage of the range from 0.0348 radians/second to 1.257 radians/second in 28 steps. Table I, lists the gear ratios and the corresponding frequencies. The available frequencies are nearly evenly distributed along a logarithmic frequency scale, thus being compatible with the usual form of input used in frequency response analyses.

Mechanical generation of the very low frequencies was chosen over the more obvious electronic generation for three reasons: first, the use of a synchronous motor and gearing assures that the frequency will be known with high accuracy; second, implementation and matching of the frequency generator to the heater power system involves less engineering effort and less cost than would be required with electronic means; and finally, the mechanical generator has enough power to drive a wide range of devices; such as an autotransformer, switches, or valves. The one real advantage of an electronic function generator, the ability to change frequency rapidly, is of no importance in this program because of the long cycle times involved in the test.

FIG. 1 GEAR LAYOUT

TABLE I

GEAR RATIOS vs. CORRESPONDING SHAFT FREQUENCY SPEEDS
FOR 72 RPM INPUT, FIXED 6:1 REDUCTION BEFORE CHANGE GEARS

GEAR RATIO		FREQUENCY (#1:#2 = 70:70)*		FREQUENCY (#1:#2 = 20:120)*	
#3	#4	Rev/Sec	Rad/Sec	Rev/Sec	Rad/Sec
70	70	0.2000	1.257	0.0333	0.209
68	72	0.1889	1.187	0.0315	0.198
65	75	0.1733	1.089	0.0289	0.182
60	80	0.1500	0.942	0.0250	0.157
55	85	0.1294	0.813	0.0216	0.136
51	89	0.1146	0.720	0.0191	0.120
47	93	0.1011	0.635	0.0168	0.106
43	97	0.0887	0.557	0.0148	0.0928
40	100	0.0800	0.503	0.0133	0.0838
37	103	0.0718	0.451	0.0120	0.0752
33	107	0.0617	0.388	0.0103	0.0647
28	112	0.0500	0.314	0.00833	0.0523
23	117	0.0393	0.247	0.00655	0.0412
20	120	0.0333	0.209	0.00556	0.0348

* FIXED GEAR RATIO OF #1 AND #2 GEARS

IV. EXPERIMENTAL STUDIES

A. Test Element

An experimental element containing ZrO_2 , to simulate the fuel, was assembled. ZrO_2 was selected, after consideration of other ceramics; based on its ability to operate at high temperatures; its crystallographic structure which is similar to UO_2 and its comparable microstructure with UO_2 . Further, ZrO_2 is free of phase changes in the temperature range of interest, is an electrical insulator and has a thermal diffusivity which is significantly different from that for UO_2 . A slip fit clearance of about 0.005 cm between pellets and cladding was used. The primary purpose of this assembly was to explore the problems of instrumentation, inasmuch as prior experience has been gained with essentially steady-state temperature measurements. Type K thermocouple wires, each 0.012 cm in diameter and insulated with "Teflon"* TFE-fluorocarbon resin, were spot welded directly to the stainless steel cladding. Four thermocouples were used at the center, 3.8 cm left of the center, 6.3 cm left of center, and 3.8 cm right of center. A fifth thermocouple had been applied, 6.3 cm right of center, but failed during installation. The entire assembly,¹ consisting of test element and cooling jacket, was contained in a helium atmosphere.

* DuPont registered trademark

(1) CEND-3336-237 "Development and Testing of a Temperature Transient Method for Performing In-Pile Thermal Conductivity;" C. E. Burdg, April, 1965.

B. Test Program Input

An axial heater was used to control the test element power to a desired base level; superimposed on this level were three basic inputs, a step input, a pulse input and a cyclic input. These input signals were used for the exploratory testing.

The thermocouple output voltage was recorded on an X-Y recorder, which was operated in the X-time mode. A selector switch permitted the choice of one or another of the four thermocouples to be recorded. The balancing system of the recorder is sufficiently fast as to contribute negligible phase shift to the signals of interest.

The step input was initiated after a base heat power level of 100 watts was established. The power to the heater was then manually changed from 100 watts to 600 watts. It is estimated that the rise time of the power step input was on the order of 0.4 seconds, a close approximation to a true step for this test.

The second input was again a manual power change, from 100 watts input to 1000 watts, then a return to 100 watts after five seconds, forming an approximation of a square pulse. As before, the rise and fall times for power were on the order of 0.4 seconds.

The third input was cyclic. A cam-operated switch attached to the mechanical function generator controlled a power contactor, which caused the heater power to be alternately on and off. The system was adjusted to give about 67.5% "on" time. The heater power, while on, was manually adjusted to a pre-selected level. Most tests were performed with either 200 or 400 watts heater input. Several cyclic frequencies were used, by changing gearing as previously described.

FIG. 2 CLADDING TEMPERATURE vs. TIME STEP AND PULSE INPUTS

RUN No. 18 - VARIABLE FUEL CONDUCTIVITY, CONSTANT FUEL-CLAD CONDUCTANCE

RUN No. 25 - VARIABLE FUEL-CLAD CONDUCTANCE, CONSTANT FUEL CONDUCTIVITY

FIG. 3 TEMPERATURE RESPONSE AT CLAD WITH ONE SECOND PULSE INPUT

C. Test Results:

1. Step Input

Figure 2 is the recording of cladding temperature versus time, for a step input from 100 watts to 600 watts. The change in temperature at the cladding is on the order of 50°C for the 500 watt change, or about 0.1°C per watt change. It became immediately apparent that the thermocouple signal consisted of both the signal of interest and a significant amount of superimposed random fluctuation. The fluctuation is directly analogous to electrical noise, and in this time scale can be called high frequency noise. Inspection of Figure 2 shows that the noise level at 100 watt input is about 2.5°C peak-to-peak; at the 600 watt input it is about 6° peak-to-peak. Further, the lowest frequency component of the noise appears to have a frequency of about 2 radians/second, with most of the noise comprised of higher frequency components.

Analog computer curves² representing the predicted performance for a UO_2 test element are shown in Figure 3. The particular results, for a one second pulse indicates a delay of about one second from the time of start of power change until any significant temperature rise is observed at the cladding. In the present experiment, with ZrO_2 in the test element, the corresponding time delay is about four seconds.

(2) Burdg, C. E., J. R. Parrette, R. I. Brockett, and W. P. Chernock, "Development and Testing of a Temperature Transient Method for Performing In-Pile Thermal Conductivity, CEND-3336-223, October, 1964

FIG. 4 CLADDING TEMPERATURE vs. TIME FOR VARIOUS INPUT FREQUENCIES

2. Pulse Input

Figure 2 contains a recording of cladding temperature versus time, for a five second pulse input. As in the case of the step input, the noise level is dependent upon the power level. The time delay was about four seconds and the shape of the response curve is comparable to the analog computer curve shown in Figure 3.

3. Cyclic Input

Cyclic input was on-off, as previously described with a 67.5% "on" time. A convenient level of power was found to be 200 watts, as that resulted in adequate temperature changes at the cladding. The first runs was aimed at determining the frequency range of interest, that is, which frequency would result in usable cyclic signals at the cladding. In Figure 4, the lowest frequency 0.0348 radians/second yielded curves which were similar to repetitive step responses, as in Figure 2. At higher frequencies, the amplitude of the response decreased until at 0.503 radians/seconds the cyclic portion of the response was well below the noise level. (Figure 4 is on a different time scale from Figure 2). All of the curves were made using the middle thermocouple.

Using a fixed frequency of 0.106 radians/seconds, both 200 watt and 400 watt input changes were checked to determine if the signal/noise ratio could be improved at higher input amplitude. In Figure 5, at 200 watts, the signal is about 11.4°C peak-to-peak, while the noise is about 4°C peak-to-peak, for a $S/N=2.85^*$. At 400 watts, the signal is about 20.2°C, while the noise is about 8°C, for a $S/N=2.52$.

* S/N =Signal to noise ratio

FIG. 5 CLADDING TEMPERATURE vs. TIME FOR TWO INPUT LEVELS AT FIXED FREQUENCY

At a fixed frequency of 0.209 radians/second, and an input of 200 watts each of the four usable thermocouples was checked in turn (Figure 6). Inasmuch as there was no attempt made to correlate the input power cycling with chart position, no attempt was made to infer phase shifts between the responses at the several thermocouple positions.

FIG. 6 CLADDING TEMPERATURE vs. TIME FIXED FREQUENCY, VARIOUS LOCATIONS

V. DISCUSSION

It is apparent that the present system does not have a high enough signal/noise ratio to readily provide the needed high accuracy of phase measurement. In past reports,³ Figure 2, it has been shown that, for systems of interest, the cladding time lag (for sinusoidal input) could be in the range of 3 to 5 seconds, at one radian/second, and in the range of 6 to 12 seconds at 0.1 radian/second. These values represent phase shifts from 171° to 287° at one radian/second, and 34.4° to 68.8° at 0.1 radian/second. While these gross changes could probably be detected with the present instrumentation, detailed information would not be obtainable. Further signal processing, to improve the signal/noise ratio, is indicated as the most promising course to follow. Ultra-low frequency low-pass filters are now under investigation as a means of reducing the high frequency noise level.

The presence of the high frequency noise in the thermocouple signal came as a distinct surprise. It has not been conclusively demonstrated that the noise is truly a fluctuation in cladding temperature; it is, on the other hand, distinctly dependent on the surface heat flux level (Figure 3 and 5) in a manner not yet understood. Its occurrence at all locations (Figure 6) would seem to rule out local anomalies in coolant flow or in test element internals.

As expected, the amplitude of the output signal decreased with increasing frequency (Figure 4). This will not present a problem except as it bears on the above signal/noise relationship because the major interest is in phase shift between power input variations and cladding temperature variations and not their relative amplitudes.

3 Burdg, C. E., J. R. Parrette, R. I. Brockett and W. P. Chernock, "Development and Testing of a Temperature Transient Method for Performing In-Pile Thermal Conductivity", CEND-3336-229, February, 1965.

The overall results of the exploratory runs were generally as predicted, with regard to the basic shapes of the responses. Accurate measurements could not be taken because of the noise problem, the confirmation of the validity of the analytical work awaits improvement of the instrumentation system and further experimentation.

VI. FUTURE WORK

During the next Quarter, further improvement of the instrumentation is expected through filtering and other signal processing means. Experimentation will proceed on other test elements, with the intent of confirming the analytical predictions.